Demonstration of Power Electronic Building Block (PEBB1) Function, and Plans for PEBB2 and PEBB3

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Abstract

Results are presented on the US Navy's work in the Power Electronic Building Block (PEBB) program. The PEBB program seeks to develop a general purpose power controller capable of performing numerous electrical conversion functions simply through software reconfiguration. A particular power conversion topology, the auxiliary resonant commutated pole (ARCP), was developed to demonstrate this PEBB function and to test emerging semiconductor devices, namely the p-type MOS-Controlled Thyristor (MCT) from Harris Semiconductor. The following items will be discussed: brief description of ARCP theory of operation, PEBB system configuration, and the thermal management for the MCT modules. Also, test results of the circuit in both the full bridge and three phase arrangements are presented. Finally, some concluding remarks about future plans for PEBB2 and PEBB3 are discussed.

Introduction

A particular aim of the US military, as it prepares to enter the 21st century, is to take full advantage of revolutionary trends in power electronics[1]. The US Navy, under the sponsorship of the Office of Naval Research (ONR), is aggressively pursuing research and development in modular power electronics, under the Power Electronics Building Blocks (PEBB) program. The purpose of this program is to apply a *more electric* initiative in surface ships, submarines, and aircraft that will utilize the latest developments in power electronics to distribute, and transform electrical power efficiently and cost effectively.

The Naval Surface Warfare Center (NSWC) is involved as a research and development site for the PEBB initiative[5]. As such, NSWC has built one of the first electrical power converters using the latest semiconductor modules, the MCT module from Harris Semiconductor. The MCT holds great promise in power electronics circuits because of its low forward voltage drop and high current turn-off capability[2]. The converter employs the auxiliary resonant commutated pole (ARCP) topology. This circuit is one of the latest in high efficiency power electronic topologies and was built as a prototype to test the Harris devices in a three phase inverter with a goal rating of 250 kW[3,4]. A particular feature of the prototype circuit is the controller which is easily re-programmed to change the operation of the power electronics circuit. Several modes of operation have already been demonstrated with a single controller, including a DC to AC inverter, a DC to DC converter, DC and AC motor controllers, a linear actuator controller, and a rotary actuator controller.

This program will insure a steady path in the development of PEBB's that will greatly transform the use of electrical energy in the US military. This paper will present some recent progress on the PEBB program at NSWC.

ARCP Theory and Operation

The ARCP power electronics converter is a soft switching circuit that achieves low switching losses and thereby improved efficiency[3,4]. The circuit utilizes two main switches and two auxiliary switches in each pole. The auxiliary switches function to achieve zero-voltage turn-on of the main switches, with the current flowing through a resonant circuit with CR and LR as shown in Figure 1 below. The resonant capacitor, CR, in parallel with each main switch, functions the same as a snubber in other switching converters, keeping the voltage transient low across the switch during turn-off. A detailed description of the operation of the ARCP circuit can be found in reference [3].

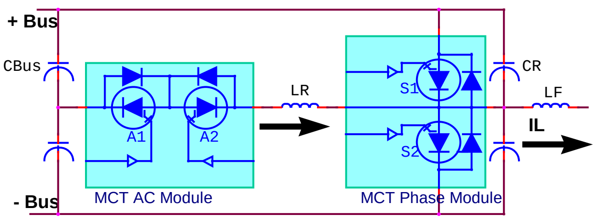

Fig. 1: PEBB ARCP Phase Leg

NSWC is presently investigating ways to achieve maximum efficiency in the ARCP circuit. In order to maximize the efficiency of the ARCP it is necessary to control the timing of both the main and auxiliary switches precisely. This allows the circuit to take advantage of load current energy to allow the main device to switch on at zero voltage. The auxiliary circuit would then provide any additional energy when the load current is small. This is achieved by sensing the load current IL and controlling the overlap-time between the main and auxiliary switches as a function of load current direction and magnitude. For example, when S1 is on and the load current IL is sufficiently high in the positive direction, the main and auxiliary switches (S1 and A1) would be on together for a brief period. However, when S1 is on and load current is negative, A1 would be left on longer in order to exceed the load current IL, and then feed additional resonant current to achieve the zero voltage transition. This amounts to a longer overlap time between the main and auxiliary switches in comparison to the low load current case. This approach is called “variable boost” to distinguish it from the case of uniform overlap time irrespective of the load current (fixed boost).

Three phase operation of an ARCP leg is implemented as shown in Figure 2 below. Also, shown in the diagram are the necessary output filter components, the inductor, LF, and the capacitor, CF.

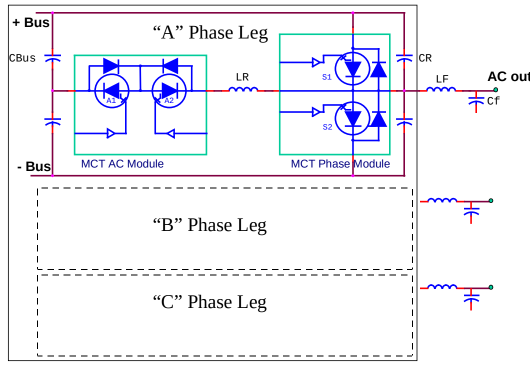

Fig. 2: PEBB Three Phase ARCP circuit

PEBB System Configuration

The PEBB consists of the following main components:

- ∗ Power Switching Section (including power semiconductors, input and output filters and gate drives)
- ∗ Control Section (including microprocessor(s), sensors, analog and digital I/O and communications circuits)

The Power Switching Section is presently configured as an ARCP. This topology was chosen for its high efficiency and capability to operate bi-directionally (power can flow in both directions). The Control Section is configured as a general purpose controller with processing power, I/O, sensing and communications capabilities which allow it to be reconfigured for a large number of control applications.

The main advantage of this arrangement is its adaptability. The unit can be reconfigured for various power conversion functions by simply changing the software. The concept is shown in Figure 4 below, with the system components shown, including a power source, the PEBB, and various loads**.** The computer included in the figure is used to communicate with the PEBB. It can be used to configure a new PEBB for an electrical application, reconfigure an existing PEBB for a different application, or retrieve operating parameters from the PEBB or the connected load.

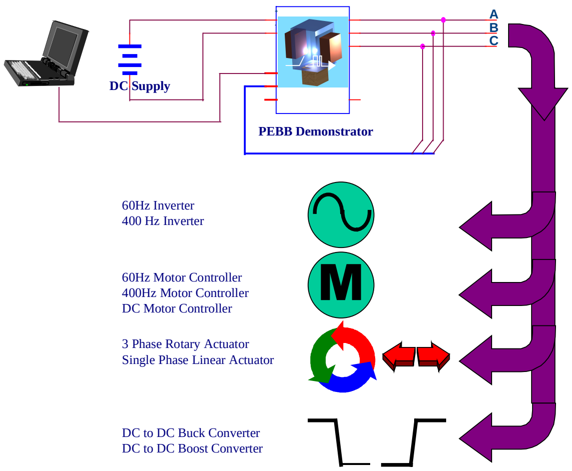

Figure 3 -- PEBB System Configuration

To date, the PEBB demonstrator has performed the following functions through software control without any hardware modifications:

* DC-60Hz 3 Phase Inverter
* DC-400Hz 3 Phase Inverter
* Variable Frequency/Variable Voltage AC Motor Controller
* Variable Voltage DC Motor Controller
* 3 Phase AC Ball Valve Actuator
* Single Phase Linear Actuator
* DC-DC Buck Converter
* DC-DC Boost Converter

When operating as an AC motor controller, the unit can ramp up the voltage and frequency using a constant V/Hz ratio in order to minimize inrush currents.

As a ball valve actuator, the PEBB senses the fully opened and fully closed sense contacts to automatically stop valve actuation. Reversing the direction of valve motion is performed by changing the phase sequence output to the three phase windings. Since this is done by the controller, it eliminates an additional set of power contacts normally needed to perform this operation.

In the case of the linear actuator, a single phase motor with two windings (one winding to extend the arm, one to retract) is connected to the PEBB. The PEBB can individually energize one winding to operate the actuator in the direction it needs to move. Analog or digital I/O on board the PEBB can be used to sense the position of the arm.

Cooling System Description

The MCT modules from Harris were designed to interface directly with water cooled heat sinks, which were also developed by Harris. For cooling in the PEBB demonstrator, the modules were arranged in three separate parallel cooling paths (one for each phase) as shown in Figure 4 below. Since the power dissipation is highest in the Main modules, the water is first routed to the Main module and then directed to the AC module. The system is designed to allow monitoring of the input and output coolant temperatures, as marked by T1 - T4 below. This allows the total per phase power dissipation to be calculated based upon the flow rate and the temperature rise from input to output. Eventually, the cooling system will be designed for six independent (parallel) coolant paths in each of the six modules, allowing the Main and AC module dissipation to be measured separately.

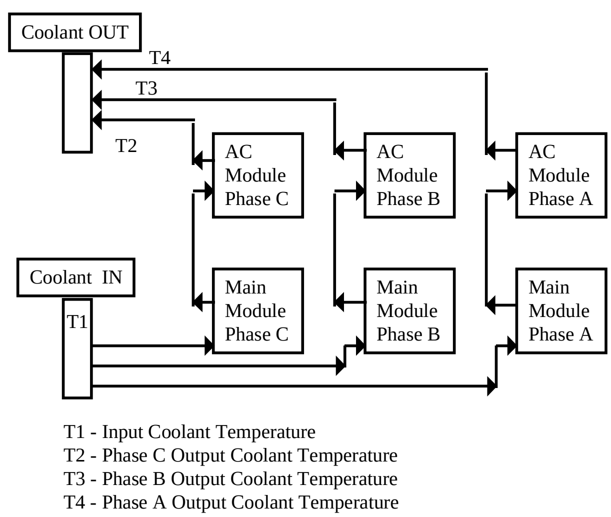

Figure 4: PEBB Three Phase Cooling System

Power Levels Achieved

The PEBB demonstrator was operated under various load conditions at various PWM switching frequencies during our evaluations. Most of the high power tests, however, were conducted with the PEBB demonstrator operating in a DC to AC inverter mode. The output frequency was programmed for 60 Hz operation, even though other output frequencies are simply changed with the controller software. Additionally, most of the tests were done at the relatively low switching frequency of 5 kHz. This allowed minimum power dissipation in the modules while various control schemes were evaluated.

Results of testing performed on two phase legs (Full Bridge) are included in the following table. The maximum power level achieved thus far at 5 kHz switching frequency was 29.1 kW. This power was achieved for an input DC level of 359 volts.

Full Bridge Power Levels at 5 KHz Switching					
	Run # Date	*DC Volts*	*Output Volts (RMS)*	*Output Amps (RMS)*	*Power Output (KW)*
Highest	220 11/14/96	359	166	177	29.1
Next Highest	219 11/14/96	359	167	160	26.5
Next Highest	217 11/14/96	359	166	160	26.4

Table 1 -- Full Bridge Power Levels

The maximum three phase power level achieved to date is 50.4 kW at a switching frequency of 5 kHz. Results are shown in Table 2.

Three Phase Power Levels at 5 KHz Switching					
	Run # Date	*DC Volts*	*Output Volts (RMS)*	*Output Amps (RMS)*	*Power Output (KW)*
Highest	235 11/25/96	359	171	171	50.4
Next Highest	234 11/25/96	359	171	167	49.3
Next Highest	240 11/25/96	399	192	141	46.7

Table 2 -- Three Phase Results

Future Plans

The PEBB program is divided into three phases over several years. PEBB1, the first phase, which was described in this paper, focused mainly on PEBB functions, circuit topologies, and the universal controller. PEBB2, which is underway in 1997, will focus on reducing the size of the PEBB components and achieving standardized interfaces and “foot-prints." Still further out in time, PEBB3 will focus on commercially available packaging and full PEBB implementation.

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